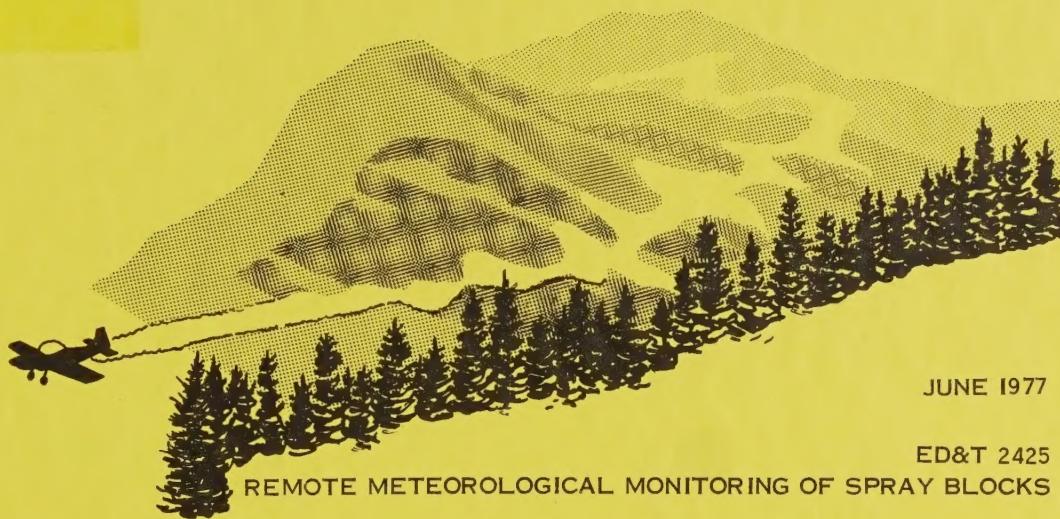


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REMOTE METEOROLOGICAL MONITORING OF SPRAY BLOCKS

meteorology & pesticide application



**U.S. Department of Agriculture
Forest Service
Equipment Development Center
Missoula, Montana**

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METEOROLOGY & PESTICIDE APPLICATION

ED&T 2425

REMOTE METEOROLOGICAL MONITORING OF SPRAY BLOCKS

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June 1977

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Meteorology and Pesticide Application¹

Abstract.--Problems in aerial application of pesticides to forests are described with special reference to meteorological factors. Field experiments, pilot projects, and operational projects are considered. All require weather forecasting to schedule spraying. Needs describing equipment and methods to control or measure spray behavior from release until arrival at the ultimate target are discussed. Figures are presented with several constraints that define a spray window showing best drop-size range and atmospheric conditions for spraying. The constraints have not been established quantitatively and show the need for additional meteorological research and development. A need has been demonstrated for a spraying strategist, who may or may not be a meteorologist, but will require new tools from the meteorologist.

INTRODUCTION

I've been involved in developing equipment for aerial application of insecticides in western forests since 1964. I certainly welcome an opportunity to share some thoughts I have developed over this period, particularly in the unfilled needs in delivering pesticides from the air to the forest canopy.

I would like to begin with a quotation from Dr. Peter Southwell, who is with the School of Engineering, University of Guelph, Ontario, Canada. This is a quotation from an address given by Dr. Southwell at the Fifth International Agricultural Aviation Congress in Warwickshire, England:

"The evidence suggests that precise definition of target surface and thence prescription of the optimum droplet size and number of droplets for a particular circumstance could lead to tremendous increases in the efficiency of pesticides usage. In order to achieve this, though, we need to understand a great deal more about the spatial dynamics of insects, about micrometeorology within and above crop canopies and about the behavior of droplets. The first of these paths to progress is the preserve of the biologists amongst us, and their colleagues. The second emphasizes the urgent need for a

much greater input to bio-aeronautics by the meteorologists. The third path lies in the territory of our physicists and aerodynamicist friends, and I hope they will be persuaded to collaborate with the meteorologists in studying the performance of foliage canopies as a droplet filtration system."

Dr. Southwell is speaking about aerial application in general, including agricultural crops, forestry, and public health, but I think that his remarks are particularly pertinent to our forestry application. Dr. Southwell very pointedly mentions the need for interdisciplinary cooperation. He points out not only the need, but the possibility of tremendous progress. This progress, however, is dependent on interdisciplinary cooperation and he especially emphasizes the need for the meteorologists as well as the physicists and aerodynamicists.

Here are some observations on the state of the art in aerial application within the United States. I do not know of any forestry aerial application group within the United States, conducting comprehensive research and development, that has a full-time meteorologist on its staff. Some of the organizations doing what I would call comprehensive research and development have people from other disciplines

^{1/} This report was originally presented as a paper at the Fourth National Conference on Fire and Forest Meteorology, Nov. 15-19, 1976.

who work in the field of meteorology, who take meteorological measurements, who attempt meteorological interpretations, but are not professional meteorologists.

We know that one of the most important aspects of aerial application in forestry is selection of proper drop size. We also know that selection of proper drop size and production of that particular drop is one of the most, I might say controversial, but perhaps I should say most discussed questions. For most forest insects and pesticides the entomologist cannot tell us the precise drop size that he would like to deliver to the target. Even if the entomologist could specify the drop size, the meteorologists and physicists cannot tell us precisely how to deliver that drop size to the target; and even if the meteorologists and physicists were able to tell us how to deliver this drop size, the engineer cannot tell us how to produce this drop size and what the effect of aircraft wake is upon delivery of the drop.

Dr. Southwell says that there is a tremendous area for progress. I mentioned some of the lack of progress and I would like to continue to discuss the problems from the standpoint of delivery of insecticides. I would like to go on to a discussion of some of the progress made in solving these problems and how this variety of problems might be organized for an efficient attack by those biologists, scientists, and engineers. Finally, I would like to draw a scenario of how the future spray project might be conducted when you gentlemen and your colleagues have solved some of these problems and have made the solutions available to the forester who is charged with the responsibility for managing the insect population.

I am not here to ask you as meteorologists and specialists in fluid dynamics to solve all of the aerial application problems; I am certain that efficient solution of the meteorologically related problems cannot be attempted without some knowledge and appreciation of the variety of problems that beset the aerial applicator. Therefore, I am going to present an entire array of problems and leave it to your judgment which ones you feel the meteorologists can most efficiently attack.

PROBLEMS AND PITFALLS

Chemical sprays have been used to control insect and disease in agricultural crops for

many years. Literature abounds with results of research and new equipment as well as techniques developed for spraying cropland. From the standpoint of control, aerial chemical spraying of agricultural cropland has been very successful. Techniques and equipment developed for aerial spraying of croplands have been adapted to aerial spraying of the forests; sometimes successfully and sometimes unsuccessfully. Forest spraying presents many problems not found in normal agricultural spraying: The target is a dense three-dimensional canopy; the terrain is usually irregular; convective winds are frequently prevalent; the aircraft cannot fly close to the crop; the crop is usually a low-value crop compared to agricultural crops; there is frequently high-quality water nearby; there is difficulty in marking ground locations.

Let us look at some problems facing an applicator spraying forest insect larvae in the western United States:

1. Because of the concentrating effect of mountain valleys and canyons, significant concentrations of insecticides can be carried several miles.
2. Instead of falling a few feet as in the case of cotton spraying, forest insecticides must travel 50 to 250 feet vertically to reach a target. Losses, due to evaporation, become more significant both in terms of greater drift and loss of insecticide.
3. The dense forest foliage may capture all of the insecticide within a few feet, resulting in only one side of the tree being sprayed.
4. On the other hand the drops may be so small that they are deflected around the target by aerodynamic forces.
5. Some lateral displacement of the spray is beneficial, but if the displacement is excessive the applicator cannot predict where it will reach the forest and has lost effective control of the spray.
6. In his zeal to prevent excessive lateral displacement, the applicator may select drops so large that too few numbers of drops are available for effective coverage.
7. It is difficult to fly evenly spaced swaths over large, irregular tracts of forest having few roads or identifying boundaries.

8. Steep slopes present several problems. The actual surface area is greater than shown on a map, the downhill side of the boom may be 50 feet higher above the trees than the uphill side of the boom. Flight path and direction are limited because the aircraft cannot climb steep slopes, instead the aircraft usually flies contours.

9. Rough, irregular terrain is usually associated with steep slopes. If the applicator flies a level path his altitude above the terrain varies continuously; if instead he follows the terrain, roller coaster fashion, his speed and application rate vary continuously.

10. In an effort to obtain better coverage, the applicator may increase the volume of insecticide carrier without giving adequate consideration to the lethal drop size, requiring hundreds of drops to kill a larva rather than one drop.

11. The aircraft wake, whether it be wingtip and propeller vortices from a fixed-wing or rotor vortices from a helicopter are a major influence on the spray behavior. Small drops are entrained in this cloud and transported in a manner similar to smoke ring movement. Other larger drops fall independently of the vortex but are not readily visible. Thus, the applicator may be misled by observing the visible cloud.

12. In 2 hours of morning spraying the stability conditions usually vary from spraying under an inversion to neutral or unstable condition. The applicator will not be aware of these changes.

would be encountered in a control project. The equipment must be large enough to be used on a larger scale control project. Then candidates that have passed these phases, have met the requirements of the Environmental Protection Agency, the Department of Agriculture, and the Forest Service are available for control projects which are a management tool of the forester.

At the first level of usage, laboratory screening, we see a place for the meteorologist in assisting the biologist in the design, construction, and operation of the spray chambers and in the conduct of wind tunnel experiments. In field experiments the meteorologist can be expected to play a very important role because usually we have a large number of chemicals or pesticides, the plots are small, and there is a need to demonstrate that comparisons of various pesticides have been conducted under sufficiently similar meteorological conditions to provide a proper comparison. Since the spray plots are small, delivering the material to a small area is frequently much more of a problem than when substantial amount of drift and swath overlap is useful on a large spray project.

In a pilot control project, one of the important roles served by the meteorologists is in providing weather forecasting. These projects are usually quite expensive and yet they provide no direct economic benefit to the forest manager because they are not established to control insects, so the minimization of cost is very important. The meteorologist can give us accurate weather predictions so that the materials can be applied under the desired conditions and the mobilization of equipment and manpower is done on an efficient basis.

A further important role is as an advisor to the project officer on strategy and tactics for delivering the insecticides. This has been a role that we have seldom seen a meteorologist in but one that I think is going to be of increasing importance.

The control project itself has all of the same problems that a pilot control project has, but in addition it is probably more subject to public criticism and scrutiny. It involves dispersion of much greater amounts of pesticides, therefore every phase of the application from delivering the minimum amount of insecticide to a given area and concern with off-target risks are extremely important. Again there is a role for a spray strategist.

NEED FOR RESEARCH AND DEVELOPMENT IN EQUIPMENT AND METHODS

We do not know all of the things that need to be measured in the field and we do not know how frequently or where they need to be measured. However, we can make some general statements.

Battery-powered Equipment

Equipment should be portable and since we need information from several locations it should be as inexpensive as possible, compatible with the quality of information. There is probably a need for a telemetry system that can accumulate real time data from a variety of points within a spray area and transmit it to the project director. We also know that simply making meteorological measurements at or near the ground level is not sufficient; that there is a definite need to have some information in the regions above the canopy and near the release line of the aircraft. We've worked with two types of system here at the Equipment Development Center in Missoula: Tethered balloons which either transmit information via a wire or via a radio signal. We've also used portable towers and it has been my own experience that the towers that are available are too slow, too cumbersome, not sufficiently portable to be useful. My own opinion is that for measurements in the region above the canopy, tethered balloons are definitely preferred.

Some of the things that affect spray behavior are turbulence, windspeed, wind direction, and temperature; here again not just at ground level but the entire region from release at the aircraft to the impact on the target.

Weather Forecasting

Under Methods Development, the first item to consider is forecasting. For most of us nonmeteorologists when we think of meteorology we think of weather forecasting. As a result of the efforts of the combined forestry and meteorology groups there are available the tools and the administrative procedures that have been developed in connection with fire control to provide weather forecasting service to aerial spray applications. We have found fire weather forecasting to work extremely well. The quality of weather forecasts is going to depend generally upon developments on a much broader scale in the state of the art in knowledge in forecasting weather. So perhaps one of the biggest improvements that might be made is in providing additional information to the weather forecaster. Can we provide additional, faster, more specific information about the particular spray sites to the weather

forecaster so that he can give us improved forecasts? Generally there are two periods when we expect a forecast from the meteorologist--(1) in the evening before spray day, final decisions are made as to what areas will be sprayed, where the people will be deployed, how much material will be mixed, and at this point it is very important to have the most up-to-date forecast information for decisionmaking about the following day's activities; and (2) just prior to spraying. Now, unfortunately, this usually occurs at 4:00 or 5:00 in the morning. But at this point new weather patterns may have developed and a decision must be made quickly on whether to spray or not to spray that day. So it's very important that we have the weather forecaster and his best knowledge and judgment available to us at that particular time.

Air-to-Air Spraying

I would like to touch briefly on air-to-air spraying. To the best of my knowledge there has been no air-to-air spraying of forest insects conducted within the United States. However, an extensive research program is being carried out in New Brunswick, Canada. The basis for the air-to-air spraying of the spruce budworm is to spray the adult moth before she can lay her eggs in a previously uncontaminated area. It involves radar tracking of clouds of moths, as well as the tracking of wind systems, followed by predictions of where within the air space to deliver a swath of pesticide that will make contact with the adult moth in the air. In this type of operation even more than in normal spraying, the close cooperation between the biologists, meteorologists, engineers, and aerodynamicists is very important. On this topic I would leave you with the question that if air-to-air spraying of the spruce budworm in the Province of New Brunswick is successful, should the similar technique be investigated for application within the United States, both in eastern forests and in our western mountainous region? Here the most important starting point in the air-to-air spraying is understanding the activities of the moth as related to time, space, and meteorological conditions. Therefore I think we probably could expect the leadership to come from the biologists.

Control of Drift

There has been a large amount of research done in the control of spray drift and contamination of nontarget areas by the agricultural researchers. Most of these tests have been done in relatively flat agricultural areas. Within our mountainous terrain I am sure that many of the same techniques can be applied; certainly the same type of monitoring equipment, but within the mountainous regions we're sure that insecticide drift is concentrated by the

channeling of airflow through canyons and valleys.

This would appear to be a formidable array of problems. It is also a tribute to the aerial applicators that they do carry on successful spray projects despite these problems and the lack of knowledge in some of the areas.

AN APPROACH TO ORGANIZING THESE PROBLEMS

In figure 1 we show the effect of a droplet being carried so far away that it is essentially beyond the control of the applicator. Here we have a plot of droplet diameters versus windspeed above the canopy. The shaded area to the left is the area in which the drops would be carried too far. I've somewhat arbitrarily chosen 1,000 feet as too far. In some circumstances it would be more and in some less. We see that there is an area on the right within which the drops can be contained and an area to the left which we want to avoid.

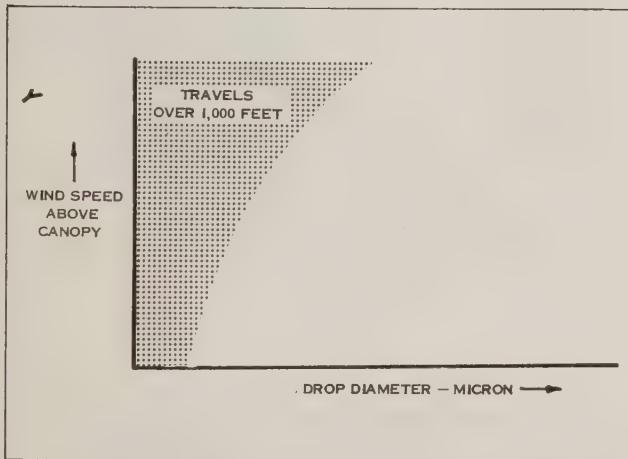


Figure 1.--Excessive swath displacement.

Figure 2 shows another aspect of the problem. This is a representation of the fact that the droplets will not penetrate the canopy. That is they will be very effectively filtered out by the first foliage that is encountered and cannot be uniformly deposited throughout the canopy. In this case the permissible area is on the left. The avoided area is on the right and again it's a plot of drop diameter versus windspeed above the canopy.

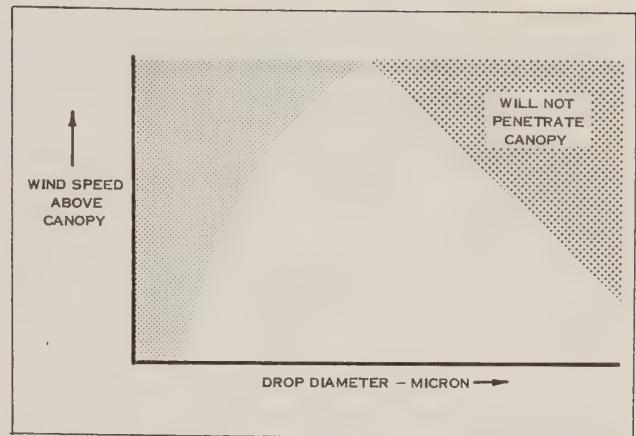


Figure 2.--Drops too large to penetrate canopy.

In figure 3 we have the same coordinates, but we demonstrate the area in which there are not sufficient drops available to provide adequate coverage. This is of course based on some reasonable amount of total volume of material being delivered. Again the area on the left is suitable; the area on the right is to be avoided.

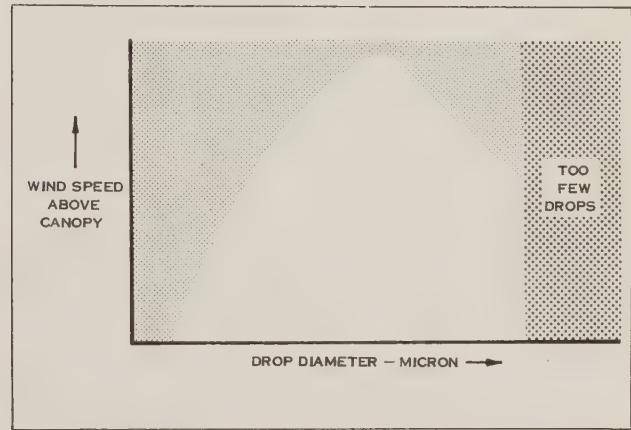


Figure 3.--Too few drops for coverage.

Figure 4 shows relationship between windspeed and drop size for one value of turbulence. In figure 5 we show the area where because the windspeed is too low and the drops are too small, they will not impinge on the target. In this case the target might be considered to be either foliage or an insect. The area on the right is permissible; the area on the left is to be avoided.

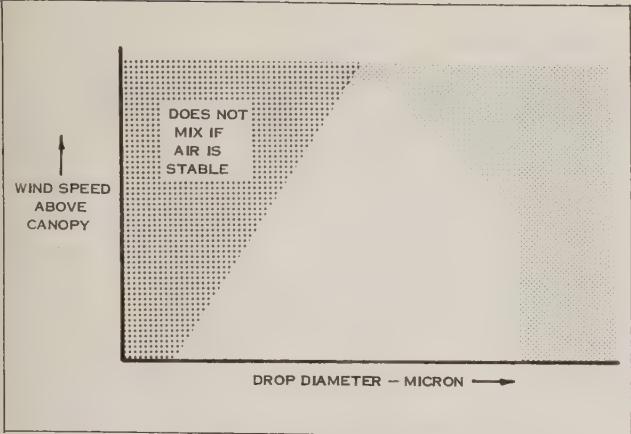


Figure 4.--Lack of turbulence affects deposition.

In figure 6 we chart all of these curves on the same graph we find that in the center is the permissible area bounded by several areas that are not useful. Here again notice that we have not placed any values on drop diameter or values on windspeed. However, we know a general range for these values and demonstrate that when all of these constraints are considered together there is one open area that is permissible. We also feel pretty certain that this permissible area is broken up into two areas. On the left side the drops are so small that they are principally airborne. Their terminal falling velocity is so low that they are essentially carried wherever the wind takes them; whereas the right side represents larger drops. These large drops are affected by air movements but their arrival at the target is primarily through gravitational settling.

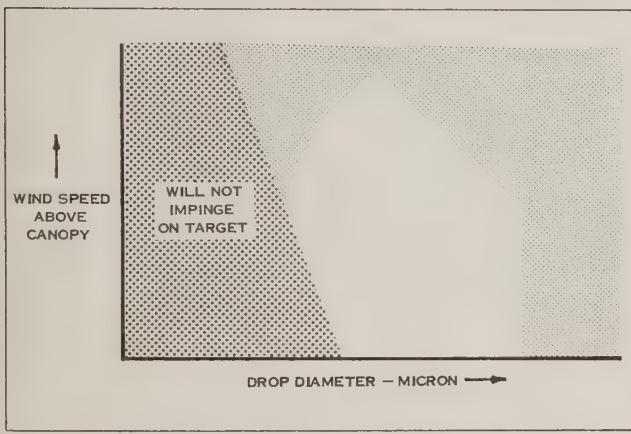


Figure 5.--Drops are deflected around target.

These figures demonstrate the possibility of a rational approach to this entire problem where a multitude of factors can be considered together and it also shows that the problem is complicated by the fact that the physical behavior of the drops in the optimum range is essentially governed by different sets of equations; one being the airborne particles and the other being the particles subject primarily to gravitational settling. I would also like to point out that there are other factors that affect the optimum drop range that are not included: Evaporation, effect of aircraft wake, and the electrostatic attraction of the ground and foliage for the drops.

Spray Strategist

There are some very severe constraints imposed upon a large operational spray project. The period during which the insect is susceptible to the material being applied is relatively short. The time of day and number of days with weather suitable for spraying may be relatively brief. The number and types of aircraft that are available for a short duration project are definitely limited. These are constraints that very little can be done about.. However, at the same time, by understanding the physical phenomenon that are governed by basic scientific principles we can spray more effectively, reduce damage to the environment, and in some cases increase the period of time available for spraying.

I feel that the principles involved and the expertise are sufficiently complex to warrant the training of a spray strategist. I'm not suggesting that the spray strategist be a primary title, nor am I suggesting that the person need to be a meteorologist or physicist or engineer. However, I believe that the physicists, aerodynamicists, engineers,

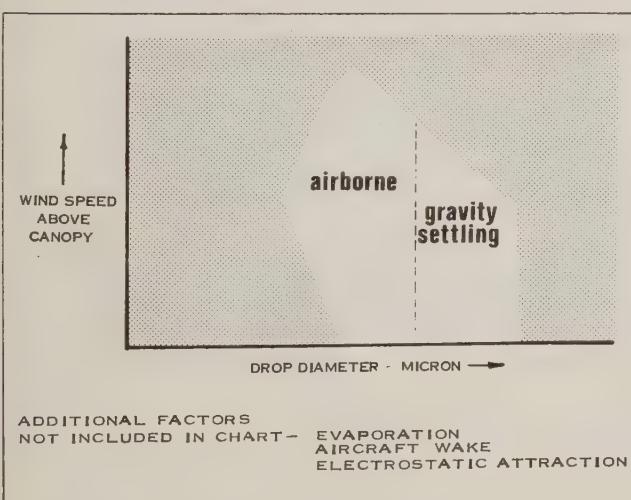


Figure 6.--Envelope of optimum drop size.

meteorologists, entomologists must develop the body of knowledge and ultimately provide training to a spray strategist who will be available as a staff position to a project control officer.

Sample Spray Project

During the Northern Region pilot control project for spruce budworm in western Montana in June 1976, we applied some of the principles of spray strategy. We think that the principles were applied successfully and contributed to the success of that particular spray project. The principles and body of knowledge that are necessary for good spray strategy have not been completely developed. However, I would like to give you some examples of how spray strategy might be employed.

This was a spray project that was conducted on National Forest land that was rough, steep, irregular terrain. Spraying followed the conventional practice of spraying early in the morning and continuing spraying until either a plot was completed (these plots were about 2,000 acres), or until the winds appeared to be unfavorable. The spraying was done with a turbine-powered helicopter with rotary atomizers.

Now, some examples of what we did:

- We made a study of seasonal weather patterns in the area.
- The pilot was required to fly a reconnaissance of each spray area prior to the day of spraying, and submit a map of his selected direction, length and order of spray swaths.
- A meteorologist reviewed the flight plan and gave the pilot an estimate of wind-speed and direction and estimates of when windspeed and direction would change.
- Ridges were sprayed during the first 30 minutes of daylight when downslope winds were in effect. It is almost impossible to spray ridges after upslope winds are well developed.

- Windspeeds were measured both at ground level and 50 feet above the canopy during spraying.
- Whenever possible the aircraft was flown crosswind to enhance overlapping of swaths.
- Based on model calculations the pilot was instructed how much to offset from the spray boundary to compensate for swath displacement.
- Special attention was given to areas that had converging gradient and slope wind fields.
- Actual swaths flown by the spray aircraft were plotted on an aerial photo by an observer in a chase helicopter.

These are a few of the things that can be done based on today's knowledge and equipment.

For the future one can imagine many things within the realm of today's technology.

- Electronic guidance for spray aircraft that also operates a plotter at ground station to show swath patterns on a map.
- Computer generated maps of predicted drainage wind flows for each hour of the day.
- Several remote locations where windspeed, wind direction and temperature are measured and automatically transmitted to a central station.
- Spray equipment that can be quickly adjusted to provide drop sizes to suit a newly observed meteorological condition.
- A remote sensing monitor for detecting excessive off-site spray drift.
- But perhaps most important, a well trained spray strategist who can access this information, interpret the information and provide the project director the best guidance on how to deploy the spray equipment.

CONCLUSIONS

1. There is a great potential for improving aerial delivery of insecticides.
2. Most of the major problems are readily identifiable.
3. Technology for solution of the problems exists but must be applied in a creative, innovative manner.
4. Timely efficient solutions require a comprehensive program directing the efforts of an interdisciplinary team.

In closing I would like to once more quote Dr. Southwell:

"We need to keep our feet on the ground, as well as our head in the clouds."

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